Library Progress International *Print version ISSN 0970 1052*
Vol.44, No.6, Jul-Dec 2024: P.611-618 *Online version ISSN 2320 317X*

Original Article *Available online at www.bpasjournals.com*

Solar Photovoltaic Power Projects – Contribution and Challenges in Indian Power Sector

Bala M. Vigneshwaran [1], Dr. Rituparna Ghosh [2]

How to cite this paper as: Bala M. Vigneshwaran, Dr. Rituparna Ghosh (2024) Solar Photovoltaic Power Projects – Contribution and Challenges in Indian Power Sector. *Library Progress International, 44(6) 611-618*

Abstract:

This study explores the role of solar photovoltaic (PV) power in India's energy sector. This specifically focused on the contributions, challenges, and potential for sustainable development. Through a thematic analysis of recent literature, the research explores areas like technological advancements, policy frameworks, financial barriers, environmental impacts, and integration plans. Findings also revealed that while India has made significant progress in the promotion of solar PV adoption through policy incentives and technological innovations there are substantial barriers. High initial costs, and regulatory constraints, followed by grid stability issues are some of the important challenges that need proper care. Proper acknowledgment of these obstacles through strategic policy changes, financial mechanisms, and infrastructural upgrades could improve solar photovoltaic power deployment across the nation. The study concluded with recommendations to nurture a supportive ecosystem for solar adoptability growth. This ultimately contributes to India's renewable energy targets and climate goals.

Keywords: Solar photovoltaic (PV) power, India energy sector, renewable energy, and sustainable development.

INTRODUCTION

In the recent digital age, there is a growing importance of solar photovoltaic (PV) power within the shifting energy profile in India. The commitments toward a sustainable India on a global scale include a significant amount of dependence on renewables in India. Therefore, to attain sustainability solar PV specifically provides a good amount of potential due to its abundance, scalability, and decreasing installation costs. This research highlighted the multifactorial role of solar photovoltaics within the energy sector of India (Chandel et al., 2022). This helps to evaluate the impact of this technology on power generation, employment, along economic growth. During the acknowledgment of the associated barriers, there are restrictions on their large-scale adoptions.

One of the main purposes of this study is to observe the contributions along with the challenges imposed by solar photovoltaic power in the energy sector in India. Therefore, the study demonstrates the possibilities and limitations in an elaborate manner. The study includes the investigation of the ability of the current policy frameworks (Rathore & Panwar, 2022). Additionally, it has captured the progressions and barriers of technology along with that it also has covered the financial factors that have an impact on growth. The scope of this study was wide and narrow at the same time. This study has concentrated more on knowledge contribution regarding different sectors and the impact they have had on sustainability, employment, and economic resilience generated by solar PV.

The objectives of the study provided a structured approach toward acknowledgment of the aim by breaking up the focus into significant areas of exploration. Initially, there is an exploration of the contribution of solar photovoltaic to India's power generation followed by the effectiveness to improve the security of energy flow in the country. The second consideration was regarding the

identification of the challenges present in the growth of solar PV (de Oliveira Azevêdo et al., 2022). There are considerations of confinements and constraints. The study also included the descriptive exploration of the state-level policies that were adopted across North, East, West, and South India for the determination of the localized influence of approaches on photovoltaic uptake rates.

Therefore, the significance of this research is mainly oriented towards its ability to contribute toward a deeper understanding of the role of solar photovoltaic within India's energy transformation. India has taken significant steps toward the adoption of renewable energy (Rathore & Panwar, 2022). In addition to that considering that India was embarking on ambitious renewable energy targets, it become very important to include an effective blend of innovation, policy support, and financial incentives to ensure success within the solar photovoltaic sector.

One of the most significant areas was that the study was established by knowing the limitations. As the study is based on secondary sources, most of the literature used has a good chance of containing biases from the literature that was based on policy orientation or case studies of successful examples. Another problem found was the aspect of data availability as the statistics were oriented toward the implementation of the solar PVs and information on policies as well differed across regions and sources. On the other hand, these limitations highlighted the requirement for future studies that directly depend on primary data collection for more precise information.

This study has incorporated a foundation for the investigation of the role of solar photovoltaics within the renewable energy journey in India. This is oriented with an organized framework important for the evaluation of contributions, challenges, and impacts from policy. A thematic focus was on policy, technology, and financial constraints providing a holistic overview regarding the adoption process of solar photovoltaic in India which is important for future planning and sustainable development.

LITERATURE REVIEW

India has focused on significant steps to develop the technological efficiency of solar photovoltaic (PV) for better prospects which help to reduce costs and develop the way for further distribution across a diverse landscape and climate. A well-organized study by Rathore and Panwar (2022) listed some of the important developments within the technologies for solar energy. The main considerations were in terms of innovations including materials and design that will improve efficiency and adaptability. National policies that support the technological improvements, and socio-economic factors, along with the implications of the COVID-19 pandemic also form part of the research done on the solar industries.

Other comprehensive reviews done by Shalwar et al. (2022) highlighted a number of methods to improve the performance of solar photovoltaic systems. These were elaborated in terms of material development along with the advanced cooling technologies to prove critical performance optimizers under the diverse climatic conditions of India.

Gupta and Rathore (2021) highlighted the integration of cooling technologies, which acknowledged the problem of efficiency loss within the photovoltaic systems due to temperature. These are very relevant for a hot and humid climate. This was very relevant for India. All these studies, combined to indicate the requirement of both technological development along with the strategic policy interventions for maximization of solar photovoltaic integration.

Policies have a very decisive role in helping India to move forward to solar energy. Regarding this consideration, Chandel, and Malik (2022) discussed the recent policy interventions targeted to strengthen the installations of distributed rooftop solar PV which is an important source of decentralized energy generation in the city. Such interventions included the incentives within the terms of finance, and ease of regulatory compliance, which help to support the grid integration.

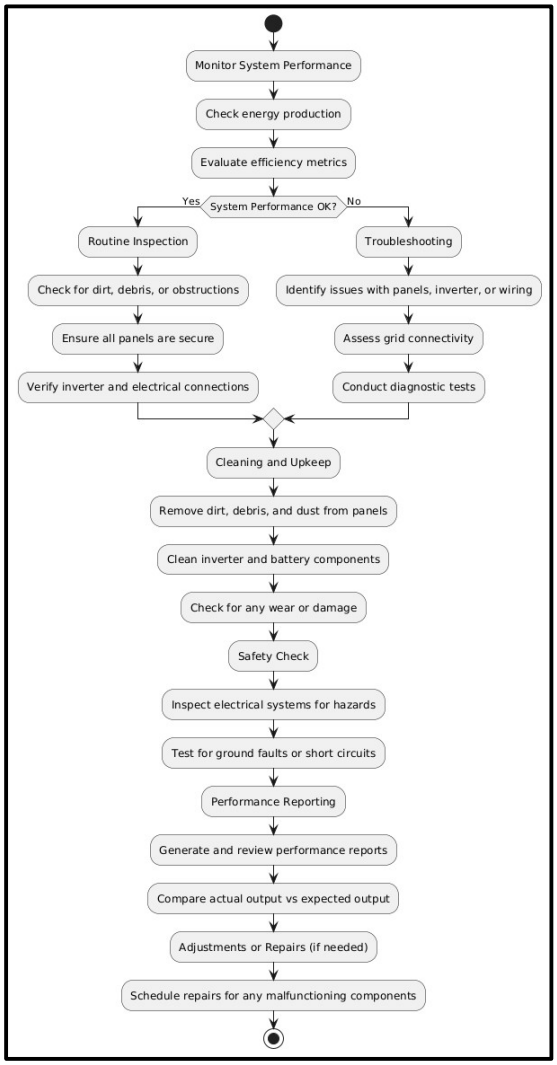

Figure 1: Operation and maintenance process of solar photovoltaic (Source: Created by the author)

This paper also analyzes India's unique approach to off-grid solar power to include electricity in rural areas. This was focused on the local narratives along with cultural contexts that inform effective policy.

In addition to this, Sarangi and Taghizadeh-Hesary (2021) examined the policy measures and business models that have led to India's rooftop solar development. This also focused on the relative effectiveness of different support schemes to improve solar adoption within the residential and commercial sectors. These studies demonstrate the diversity of the policy landscape of India regarding solar energy. Furthermore, it also adapted specifically to regional specificities while influencing sector-wide growth.

Among this integration, finance still remains one of the important issues that have extensive integration of solar PVs within India to achieve the ambitious solar energy targets. A well-structured study by Delapedra-Silva et al. (2022) has discussed the review of financial appraisals for renewable energy projects with a particular focus on the capital costs and entangled funding requirements of solar photovoltaic installations. Considering the effective continuation of the solar projects, there is a requirement for strong financial mechanisms. Furthermore, Rout et al. (2021) also considered the financial sustainability of different rural grid electrification pathways in India. The author also

highlighted that even though subsidies and financial incentives have the ability to reduce the initial costs for projects. In addition to that, the long-term sustainability may rely on the large funding along with the operational support.

Apart from this, de Oliveira Azevêdo et al. (2020) have discussed the determinants of financial viability that currency fluctuations, high-interest loans, and even limited access to capital markets are some of the important barriers to investors. The adoption of solar PVs in the country can be significantly boosted through innovative financing models like low-interest loans.

Moreover, the expansion strategy of solar photovoltaics within India was over the environmental concerns. Mahajan and Srivastava (2021) have estimated the lifecycle environmental impacts of large-scale installations of solar PV. This also reflects both the beneficial contributions towards the reduction of the carbon footprint along with the necessity to adapt well-managed waste management practices when the panels become decommissioned. Regarding this Narang and Kaur (2022) analyzed the sustainability aspects of photovoltaic systems depending on the resource utilization, environmental footprint, and waste management considerations within Indian projects. The outcome of this literature highlights the importance of sustainability in solar power systems throughout all life cycle stages including the manufacturing stage to waste.

Desai and Chopra 2023, have also investigated the ecological impacts of ground-mounted solar PV's. This also focused on the land-use transformation and biodiversity loss within the affected regions during the installation of solar photovoltaic power. This study elaborated on the solar infrastructure without compromising the environment. These studies collectively emphasized that strategies of the solar photovoltaic sector of India should be oriented towards attaining sustainability by balancing the ecological impacts with renewable energy goals.

The literature review regarding solar photovoltaics in India between 2020 and today emphasized that many dimensions are considered to achieve renewable energy targets. Technological changes help to continue to increase efficiency and system adaptability. However, a policy framework has been developed to accept proper adoption across these regions. Even though the financial barriers are substantial, they have been integrated through the utilization of the different models and government support systems within the rural and urban solar initiatives. The goals of environmental studies include the reduction of carbon emissions and the minimization of the ecological impact regarding lifecycle management in solar photovoltaic systems. This also emphasizes sustainability. In addition to that, the challenge regarding integration requires a plan and development in the area of infrastructure. Considering the adjustment towards the irregular nature of solar energy. These studies provide an overall understanding of India's solar photovoltaic sector it emphasizes the requirement for a well-balanced strategy that includes the economic, environmental, and technological elements to boost future growth.

METHODOLOGY

The investigation has adopted a qualitative approach in terms of thematic analysis of the available literature that is related to solar photovoltaic power in India. In consideration of gathering data, the following sources were resorted from online depositories such as peer-reviewed journals, government reports, and case studies. The literature knowledge was categorized into technological advancements, policy and regulatory frameworks, financial and economic challenges, environmental impacts, and grid integration. These themes were gained by considering the common challenges and contributions that were observed in the Indian solar photovoltaic sector. The review was also systematically done in 2020 to ensure that only the newest perspectives and developments are properly evaluated.

The patterns for each theme are considered with their policy impacts followed by the consideration for the technology and finance mechanisms based on India's solar industry. This has demonstrated the

methodology of in-depth evaluation those are related to the effectiveness of a policy and environment-related consequences within the solar photovoltaic sector.

This study was focused on the exploration of insights from different sources to provide an all-rounded understanding of the solar landscape in India. This is helpful as through the findings there are chances to form actionable recommendations that lead to sustainable growth in renewable energy.

Findings

Theme 1- Technological Improvement for Solar PV

The researchers have suggested that technological development for the Indian solar photovoltaic industry is in a significant stage. This is oriented toward the improvement of efficiency and adaption of technologies to local climatic conditions. The application of advanced materials and cooling techniques was pointed out by Rathore and Panwar (2022). This is helpful as it helps to reduce the adverse impacts of high temperature within the photovoltaic systems, which is a huge problem in Indian hot climates. It was found that the most emerging strategies are efficiency enhancement, specifically to consider new panel designs and bifacial modules in general, and also increased traction due to their higher output in Indian solar parks. These new advancements are very important as they assure the improvement in energy generation. Also, it helps to confirm the reliability of the system. Therefore, it is important to scale up the solar photovoltaic across different geographies.

Theme 2- Policy and Regulatory Frameworks

The three key applications for solar photovoltaics have been supported by policies in India. This was pointed out by different research that incentives and regulatory favors have recently scaled up rooftop solar stimulating the adoption in cities. According to other research, niche off-grid policies are an important aspect of incorporating electricity in rural areas where large-scale grid extension is not commercially viable. These policies, along with the improvement of the availability of solar energy, align with the satisfaction of the regional needs by promoting the decentralized generation.

Theme 3- Financial and Economic Obstacles

The huge upfront capital expenditure along with the complex funding models act as major obstacles to a more widespread adoption of solar PVs in India. Research by Delapedra-Silva et al. (2022) and Rout et al. (2021) indicated a large number of solar projects are not financially suitable. These includes the case of rural electrification tracks where subsidies become a crucial factor. Funding mechanisms like green bonds and loans with low interest rates needed to be supported for so long as investor confidence remains low as well as the general interest rate becomes unstable. These finances will thus have to be fought to create long-term sustainable viability of the project.

Theme 4- Environmental Impacts and Sustainability

The environmental impact within the case of solar photovoltaics in India has been a crucial theme for literature development. The overall sustainability considerations were considered to be more important. There are Researchers like Mahajan and Srivastava (2021) that emphasize lifecycle environmental impacts and the related benefits of carbon emissions need to be associated with waste management. Another article also placed more emphasis on sustainable practices and the disposition of photovoltaic components. The ecological effects of large-scale ground-mounted photovoltaic installations also bring out the relevance of strategic planning to understand habitat disruption and land-use conflicts as highlighted by other researchers. Collectively, these studies demonstrated the direction of solar photovoltaic expansion that requires sustainability frameworks.

Plan to implement solar photovoltaic power in India

Considering the expansion of solar PV adoption in India, the government can follow multiple steps that are as follows:

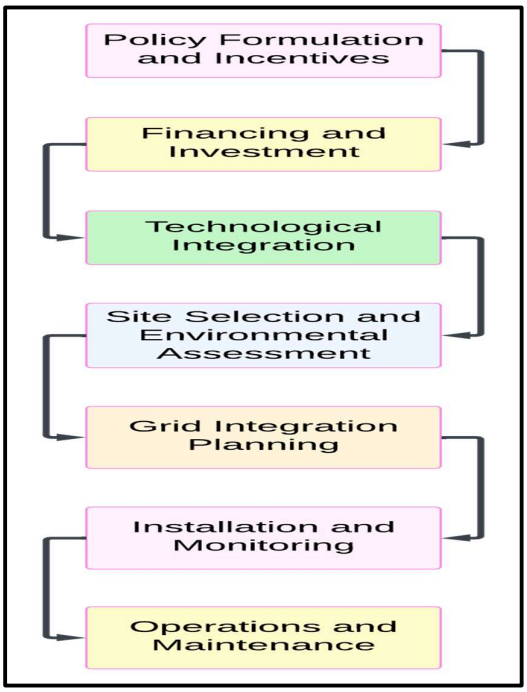

Figure 2: Solar PV Implementation Framework in India (Source – Created by the author)

Policy Incentives- Provide different subsidies and tax breaks for residential and commercial rooftop solar installations. In addition to that, it needs to be aligned with the streamlined permits to encourage participation across different sectors.

Financing Options- Development of low-interest loan schemes along with green bonds to make solar investments more affordable. This is important for small businesses and rural households.

Infrastructure Upgrades- The government bodies need to invest in smart grids and storage solutions to provide support for the stable integration of solar PV into the national grid. This assures a consistent energy supply.

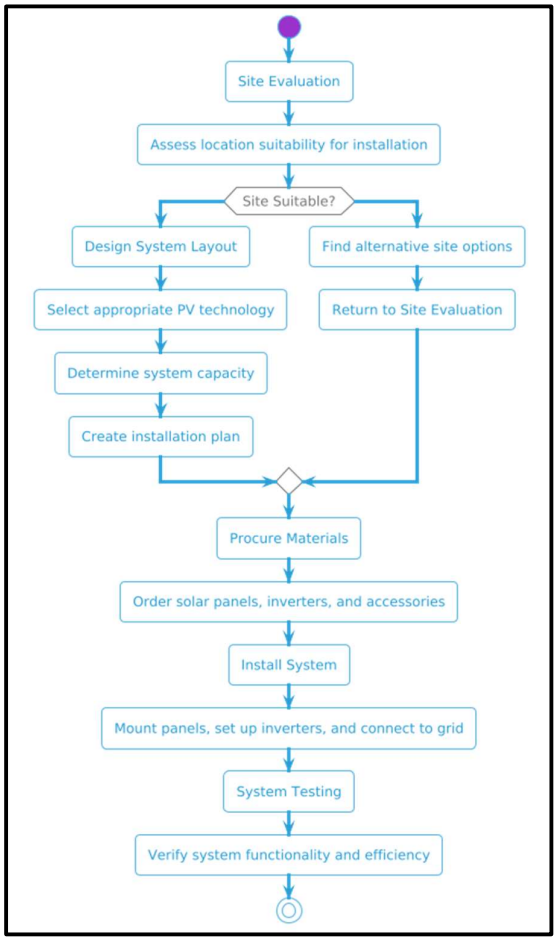

Figure 3: Solar PV installation process

Public Awareness- Launching of different types of campaigns to make the public educated about the solar benefits and available incentives. This also drives higher adoption rates across urban and rural regions.

Training Programs- This provides skill development initiatives for local communities to boost solar PV maintenance. It also will be helpful to improve the manufacturing jobs as it will support the sustainable growth in India's energy sector.

CONCLUSION

This study has provided an overall analysis of solar photovoltaic power in India. The concentrations were mainly oriented embracing the transformability and the uncertainties that have shaped the implementation. Technological advancements further improve the efficiency and reliability. These help to continuously develop solar photovoltaic power to be increasingly viable, along with diverse climates and geographies in India. Government policies are an essential part of utilizing incentives and regulations to encourage proper adoption across urban and rural landscapes. However, important cost barriers are also oriented within high upfront expenses along with sophisticated funding structures. Considering this there are customized solutions that need to be applied to achieve broad-based and sustainable growth.

Environmental concerns are also becoming critical as solar photovoltaic power expands, therefore, effective waste management in the lifecycle of solar systems. This is also oriented with the grid integration will also bring forth the unique technical issues that require infrastructure upgrades, smart grids, and hybrid systems that help to stabilize power supply and meet the renewable energy targets.

This approach will make India more beneficial toward the renewable energy future. Therefore, there will be improvement of the energy access, further supporting the economic development.

REFERENCES

Chandel, R., Chandel, S. S., & Malik, P. (2022). Perspective of new distributed grid connected roof top solar photovoltaic power generation policy interventions in India. *Energy Policy*, *168*, 113122. https://www.sciencedirect.com/science/article/pii/S0301421522003470

Delapedra-Silva, V., Ferreira, P., Cunha, J., & Kimura, H. (2022). Methods for financial assessment of renewable energy projects: A review. *Processes*, *10*(2), 184. https://www.mdpi.com/2227-9717/10/2/184

de Oliveira Azevêdo, R., Rotela Junior, P., Rocha, L. C. S., Chicco, G., Aquila, G., & Peruchi, R. S. (2020). Identification and analysis of impact factors on the economic feasibility of photovoltaic energy investments. *Sustainability*, *12*(17), 7173. https://www.mdpi.com/2071-1050/12/17/7173

Kumar, C. M. S., Singh, S., Gupta, M. K., Nimdeo, Y. M., Raushan, R., Deorankar, A. V., ... & Nannaware, A. D. (2023). Solar energy: A promising renewable source for meeting energy demand in Indian agriculture applications. *Sustainable Energy Technologies and Assessments*, *55*, 102905. https://www.sciencedirect.com/science/article/pii/S2213138822009535

Lu, T., Sherman, P., Chen, X., Chen, S., Lu, X., & McElroy, M. (2020). India's potential for integrating solar and on-and offshore wind power into its energy system. *Nature communications*, *11*(1), 4750. https://www.nature.com/articles/s41467-020-18318-7

Panigrahi, R., Mishra, S. K., Srivastava, S. C., Srivastava, A. K., & Schulz, N. N. (2020). Grid integration of small-scale photovoltaic systems in secondary distribution network—A review. *IEEE Transactions on Industry Applications*, *56*(3), 3178-3195. https://ieeexplore.ieee.org/abstract/document/9031337/

Rathore, N., & Panwar, N. L. (2022). Outline of solar energy in India: advancements, policies, barriers, socio-economic aspects and impacts of COVID on solar industries. *International Journal of Ambient Energy*, *43*(1), 7630-7642. https://www.tandfonline.com/doi/abs/10.1080/01430750.2022.2075925

Rajagopalan, S., & Breetz, H. L. (2022). Niches, narratives, and national policy: How India developed off-grid solar for rural electrification. *Environmental Innovation and Societal Transitions*, *43*, 41-54. https://www.sciencedirect.com/science/article/pii/S2210422422000168

Rout, A., Mainali, B., Singh, S., Solanki, C. S., & Bhati, G. S. (2021). Assessing the financial sustainability of rural grid electrification pathway: A case study of India. *Sustainable production and consumption*, *25*, 27-42. https://www.sciencedirect.com/science/article/pii/S2352550920302712

Sarangi, G. K., & Taghizadeh-Hesary, F. (2021). *Rooftop solar development in India: Measuring policies and mapping business models* (No. 1256). ADBI Working Paper Series. https://www.econstor.eu/handle/10419/238613

Shalwar, P. K., Gupta, B., Bhalavi, J., & Bisen, A. (2022). Performance Characteristics and Efficiency Enhancement Techniques of Solar PV System: A review. *F1000Research*, *11*, 1264. https://f1000research.com/articles/11-1264